THE STUDY OF MULTIPHASE FLOW FOR PETROLEUM PRODUCTION USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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ABSTRACT

Petroleum is a highly valued natural resource where the used are never ending and the demand will always be higher than the supply. In order to keep up with the need of the world, there should be an enhanced way to recover the oil efficiently. Therefore, the flow of petroleum or gas through a vertical pipe from oil reservoir to platform/subsea system is significant to cater the enhancement of oil recovery. This research are based on this principle, and is more focused on the study for multiphase-flow pattern of petroleum production plus the turbulent coefficient effect on the bubbly flow in vertical pipe using Computational Fluid Dynamics (CFD) software. Multiphase-flow is chosen rather than the two-phase flow because the multiphase-flow are considered to be more realistic to give more accurate result thus easily implemented to a real situation. In studying the flow pattern of the multiphase-flow, the result obtains are manipulated with varying the velocity profile of each phase and observing which phase velocity gives a better flow of oil through the vertical pipe. While for the study of the turbulent coefficient effect on the bubbly flow in vertical pipe, firstly the simulation was run on the constant of bubbly flow to obtain the flow model. In this simulation, a turbulent coefficient of k-ε was introduced so the flow model was differed from the previous investigation and the velocity of particle inside the pipe was also observed. The research was developed in an enhanced model form using Gambit software and further simulated on Fluent simulation software. The results were then compared with previous work done by other researchers. The study is considered as success when all of the objectives are achieved with tremendous results. The result obtain shown that there are only 4 type of flow found during the petroleum production in a vertical pipe obtained. The investigation found that the turbulent flow do influence the particle flow whereas the particles fall down faster may due to gravitational pull acting on the flow. This also affects the composition at the end of the pipe.

KAJIAN ALIRAN BERBILANG FASA BAGI PRODUKSI PETROLEUM MENGGUNAKAN 'COMPUTATIONAL FLUID DYNAMICS' (CFD)

ABSTRAK

Petroleum merupakan satu sumber asli yang amat bernilai di mana pengunaannya tidak pernah terbatas dan permintaannya akan sentiasa melebihi daripada bekalan. Untuk memenuhi kouta keperluan dunia, satu cara yang effisien perlu dikaji untuk mendapatkan minyak secara carigali dengan lebih berkesan. Jadi penyelidikan untuk mengkaji aliran petroleum atau gas melalui paip menegak dari pusat takungan minyak sehingga ke platform/sistem dasar laut amat diperlukan. Berdasarkan prinsip tersebut, kajian yang ingin dijalankan melalui kertas kerja ini akan lebih tertumpu kepada kajian bagi corak aliran berbilang-fasa untuk pengeluaran petroleum termasuk faktor yang mempengaruhi halaju dan profil pecahan isipadu fasa dengan menggunakan perisian 'Computational Fluid Dynamics (CFD)'. Aliran berbilang-fasa dikaji berbanding aliran dua-fasa kerana aliran berbilang-fasa dianggap lebih realistik dan dikenal pasti untuk memberikan keputusan yang tepat lalu mudah diimplimentasikan dalam situasi sebenar. Dalam kajian corak aliran berbilang-fasa, hasil kajian terbit dengan memanipulasi profil halaju setiap fasa dan memerhati halaju fasa yang akan memberikan aliran petroleum yang lebih baik melalui paip menegak. Bagi kajian kesan pekali gelora kepada aliran jenis buih didalam paip menegak, simulasi dijalan dengan menggunakan faktor yang sama dengan aliran jenis buih daripada kajian pertama.dan aliran partikel didalam paip akan dilihat. Didalam simulasi ini, satu pekali gelora jenis k-ε diperkenalkan membuatkan aliran model menjadi berbeza dari kajian pertama. Didalam kajian secara keseluruh, model ini dibangunkan dengan munggunakan perisian Gambit dan diteruskan simulasi menggunakan perisian bernama Fluent. Hasil kajian ini akan dibandingkan dengan kajian yang dijalankan sebelum ini oleh penyelidik lain. Kedua-dua kajian yang dijalankan adalah berjaya dengan kesemua objektif tercapai. Hasil kajian mendapati terdapat 4 jenis aliran didalam proses ektraksi petroleum didalam paip menegak. Kajian juga mendapati aliran gelora memberi kesan kepada aliran partikel dimana ia turun lebih cepat berbanding naik ke atas kerana tarikan graviti yang dikenakan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

LIST OF SYMBOLS

k-ε	–	SKE Turbulent Coefficient
%	–	Percent
P	–	Pressure
u	–	Velocity
T	–	Temperature
g	–	Acceleration of Gravity
ρ	–	Density
v	–	Velocity
h	–	Inclined Angle
A	–	Cross-sectional Area of Pipe
Subscript 'o'	–	Represent Oil
Subscript 'g'	–	Represent Gas
Subscript 'w'	–	Represent Water
ε	–	Volume Fraction
μ_w	–	Water Viscosity
R_{po}	–	Oil Particle Ratio

LIST OFABBREVIATIONS

CFD	–	Computational Fluid Dynamic
LPG	–	Liquid Petroleum Gas
EOR	–	Enhanced Oil Recovery
τ_{wg}	–	Gas-wall friction shear stresses
τ_{wo}	–	Oil-wall friction shear stresses
τ_{w}	–	Mixture-wall friction shear stresses
S_{w}	–	Water-wall wetted perimeter
Re	–	Particle Reynold number
C_{g}	–	Sound Velocity
i.d	–	Internal diameter (m)
L	–	Length (m)
Cp	–	Heat Capacity
F_{vm}	–	Virtual Mass Force
C_{vmg}	–	Gas Virtual Coefficient
C_{vmo}	–	Oil Virtual Coefficient
VOF	–	Volume of Fluid
F_{Dg}	–	Drag Force Gas
Mesh	–	Mashing
SKE	–	Standard k–ε (SKE) Model
RNG	–	Renormalization Group (RNG) k– ε Model
RKE	–	Realizable k– ε (RKE) Model

CHAPTER 1

INTRODUCTION

1.1 General Overview

Petroleum is one of the most abundant energy in this world where the demand is always higher than the supply. It can be proved by when the petroleum production has increased from 1.132 million barrels per day in 1999 to 1.295 million barrels of oil per day in 2001 and to 1.55 million barrels of oil per day in 2003 (Filho et. al., 2006). As we can see that the Brazil reserve and production have increased much more rapidly than the world average increases in this period. With this observation, it can be seen that the constant and significant increase is because they are trying to catch-up with the demand.

This precious energy are known to be formed according to the organic theory, where this non-renewable energy is originated from the deposition of organic matter million of years ago and as time pass by with the help of bacteria with constant constrain of high pressure and temperature have alter the organic matter into a petroleum.

Commonly in South-East Asia the oil reservoir or oil well is located under the seabed. Thus due to some factor the petroleum extracted from the earth crust will be accompanied by water. This has produced flows that are in multiphase condition because the presence of water in it. Multiphase flows, is a flow that involves more than one of the phases of matter-gas, liquid or solid, and can be found in many industrial processes (Brennen, 2005). The flow of water-oil-gas upward to the platform have cause many researchers and engineer headache because the flow are mostly water dominate in character with composition of 95 % water, 2–3 % crude oil, around 2 % gas and negligible solid particles (Sugiharto et. al., 2009). It is often economic to operate wells with over 90 % water in the output liquid flow (Chen and Guo, 1998).

This flow is hard to predict because the nature of the three different phases are vary from each other plus it can be a tedious work because some of the researcher consider the change in every pattern flow and some even consider the transition between two flow. Identifying three-phase flow patterns is crucial to many industrial problems such as pipeline installation, optimal design of artificial lift production device and interpretation of well logging data but due to the complex interfacial interaction between phases, thus the identification of oil–gas–water three-phase flow pattern is still an unsolved problem. Other than that, there most of the research made by researcher are more towards modelling a laminar flow simulation, whereas in reality the actual flow that are flowing are turbulent flow. In order to resolve this, the flow characteristic and the factor that are influencing them must be predicted.

So in order to achieve this, a Computational Fluid Dynamics (CFD) technique has been introduced so a proper model can be created and tested. Computational fluid dynamics (CFD) is a very powerful modelling tool combining fluid dynamics and computer technology. A commercial CFD program, consisted of GAMBIT and Fluent is utilize to simulate the oil-water flow. With this friendly technology, all the tedious calculation can be avoided easily with the software and human error prone can be reduce drastically. Computational fluid dynamics (CFD) is a revolutionized technique on fluid flow phenomena and some difficult-to-solve problems in fluid dynamics are now possible to be solved with the help of it (Neve, 1993).

1.2 Research Background

The study of multiphase flow has been conducted many years ago by researcher in order to predict the behaviour of this flow. The research will be more focus on the multiphase flow of petroleum that is extracted from oil reservoir through a vertical pipe to platform. This is applicable to all form of platform whether subsea or normal fixed platform. As mention earlier the multiphase of petroleum is composed of oil, water and gas needed to be optimized due to extensive use in many industries.

Many researchers have been made in order to predict the behaviour of the three-phase flow and one of the earliest is by treating the two immiscible liquids as an equivalent single phase and predicted the pressure loss with an empirical correlation (Tek, 1961). In the early 80's an optimization to this correlation are made and percolation theory was used to describe multiphase flow properties (Blunt, 2001). In 1990, Pleshko and Sharma predicted the flow pattern transition by using the model of gas– liquid two-phase flow (Taitel et al., 1980), but the result indicated that the two-phase models were unsuitable for the prediction of three-phase flow pattern transitions. Guo et. al., (1991) conducted three-phase flow experiment in a 125 mm ID pipe and divided flow patterns into bubble flow and slug flow by visual method, they subdivided the bubble flow in to two typical patterns, which were the distinguishable and undistinguishable oil droplet and air bubble.

Chen (1991) investigated three-phase flow characteristics in vertical upward pipe and classified the flow patterns on oil in water or water in oil type flow. Woods et al., (1998) conducted three-phase flow experiment in a 26 mm ID Perspex pipe; they concluded the nine flow patterns based on the water dominated and oil dominated and proposed flow pattern map. Oddie et. al., (2003) carried out oil–gas–water three-phase flow loop test, and they treated the oil–water flow as a homogeneous with no slippage between phases. With all these research, any relevant data are taken into account and is used in the project.

For the prediction of flow pattern, it is found that in every research conducted by different researchers produce a different result of numbers of flow such as Woods et. al., (1998) used a Finavestan A 50 B oil, air and water and identified nine flow patterns, while Speeding et. al., (2000) using the same fluids but only identified two new flow regimes. Oddie et. al., (2003) have observed six flow patterns when they used kerosene, nitrogen and water. However, Viera (2004) and Bannwart et. al., (2005) have observed six new flow patterns when heavy oil, gas and water flow simultaneously through a circular pipe in such a way that water is the continuous phase. The diversity in the data shows that the research is not really accurate maybe due to some neglecting of some factor.

1.3 Problem Statement

A three-phase flow research have been conducted by many research until today but there are no significant can be found on the finding between them. This difference in finding between them is may due to the different material used in the research or size of pipe utilized by them. One of the famous ways to conduct this research is by using simulation software called Computational Fluid Dynamics (CFD). This software will simulate the flow in a pipe with consideration set by the researcher. With all this research is taken into account in order to conduct a new project. Due the abundance of three-phase flow applications in the petroleum and chemical industries, a better understanding of these complex flow phenomena is needed. Other than that, until today there are no clear CFD graphics of bubbly flow produce by researchers where only illustrations are shown. Thus, all of these findings are crucial in the study of multiphase flow.

1.4 Research Objectives

The objectives of this research project are:

- to study the effect of velocity profile to the multiphase flow pattern
- to investigate the effect of turbulent coefficient on the bubbly flow movement in a vertical pipe

1.5 Research Scope

1.5.1 Introduction

In this research project, there are exactly three stages that are planned earlier before executing the project, that is:-

1.5.1.1 Stage 1

Finding journal which are related to the project and understand the core concept of the project. With the journal collected, introduction for the proposed project have been made where it is clearly stated the objective that want to be achieve accompanied with literature review. The methodology was planed. For simulation, the software was identified and the procedure of the software was learned further. In addition, the problem statement was identified.

1.5.1.2 Stage 2

During this stage, the basic concepts was mastered and focused more on the experiment methodology. Furthermore, the simulation using Computational Fluid Dynamics (CFD) technique, GAMBIT and Fluent. These techniques are chosen because it is known as a powerful and effective tool to understand the complex hydrodynamics of gas–liquid two-phase flows (Parvareh et. al., 2009). The best fit modelled plus constant was then be chosen. In this stage, the preparation for the simulation was carried in order to run the simulation smoothly. Other than that, all the variable and parameters were identified.

1.5.1.3 Stage 3

With all the variable has identified, the model was constructed using GAMBIT software while referring to the governing equation. After constructed, the models were then transferred to another software, Fluent. The investigated parameters were varied as set in the objective.

1.6 Thesis Outline

This thesis is divided into 5 major chapters where the structure is outlined according to the purpose of the research. Chapter 2 is the literature review. Here the petroleum production is brief with the composition of flow in pipe between the oil well and platform. The modelling of vertical pipeline using computational fluid dynamics are also taken into account with the governing equations involved. The characteristics of each flow inside a vertical pipe are also mentioned in this chapter. Other than that, a brief discussion about the previous research related to the flow pattern inside the pipe with the correlations and parameters of the flow pattern was stated.

Chapter 3 will focus on the methodology procedure on this research. This chapter will brief on the step taken to modelled a vertical pipe with consideration of some negligible and assumption variable that have been set up in computational approach. The study will focus on the try-and-error method by varying the velocity inlet at the inlet of pipe. Other than that, the velocity vector of flow is taken into account where it is set to be in turbulent flow after the introduction of turbulent coefficient. Here also, the variables for each research were clearly stated.

Chapter 4 shows the results and discussions where the results obtain are clearly stated and discuss with support and comparison from previous study. The bubbly flow patterns found are then shown and the parameter used are compared with previous study before the pattern can be accepted. The vector velocity are also shown for the purpose of knowing the flow of gasoil-liquid.

Chapter 5 is the last chapter of this research. This chapter conclude all the research results and some recommendation are listed for the purpose of furthering the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This project focused on the flow pattern of the multiphase flow and the flow movement in turbulent condition. A reports was made at the end of the experiment and the results of computational fluid dynamics (CFD) analysis, backed up by published experimental data, where there are applicable were presented.

2.2 Petroleum Production

Petroleum is a source of energy which is classifies as a non-renewable resources. Once petroleum is used it will converted into energy and would not be recycled back to its original state. If the oil is explored for long time there served oil will reduce or diminish. According to the organics theory, petroleum is the product of decomposition of organics residual such as animal and plant million years ago probably during the ice age or dinosaur age. The decompose buried deep under the earth and the layer of burial were thickened as time passes by. Under the earth, the organic matters were covered with mud, sand and other debris. In the periods of layer thickening, causes the pressure and temperature to increase, with the help of some bacteria it turns the decompose organics matter into oil and gas. During this period also, the mud and sand have turned into porous rock and the newly converted oil and gas flow upward and sipped through the pores until it will stop after meeting the cap rock due to the difference in density, note that there also will be water present between the pores. So below the cap rock, there will be water present at the most bottom and gas will be at the most top at the cap rock while oil will sit between the two phases.

With this, an oil reservoir or oil well has been produces and waiting to be explored but bear in mind that the quality of petroleum in the reservoir are vary from each other. The petroleum emplacement is a major control on reservoir quality in many carbonates (Scholle, 1977; Scholle and Halley, 1985; Feazel and Schatzinger, 1985). Petroleum in a reservoir can be considered to be a delicately balanced system under high pressure in so far as the different fractions are compatible and provided that there are no significant disturbances or changes made to the system (Speight, 1996). Moreover, there are still a lot of oil reservoirs which have not been discovered yet.

As year passes by, the demand for petroleum is really high and never back down because there are variety of uses and making it important to us in this world. As a simple example, mostly all cars in this world use petroleum as the power source for their engine and it will continue to be like that. As we can see that nowadays, there only just a few percent cars model that use alternative energy as power source. Other than that, petroleum also are use in tar where it is use in making roads, where in road we can find asphalt which is also come from petroleum. Petroleum also has been converted into Liquefied petroleum gas (LPG) for the easy source of fuel. In petrochemical industries, petroleum will be converted into many chemical products that will be the main ingredient in everyday life such as clothing, food, cell, and countless more. So because of this, the demand for petroleum will never back down and as the world developed from day to day the use of petroleum will increase.

2.3 Multiphase Flow Of Petroleum To Platform

A multiphase flow is a flow of material that composes of more than two phases through a pipe usually in phase of Gas, Liquid or Solid. The major difference, between two and three-phase flows, is that the presence of two immiscible liquids gives rise to a wider variety of flow patterns, which depend on the flow rate, thermo-physical properties of the fluids, inclination angle and diameter of the pipe (Cazares et. al., 2010). In the perspective of this project, it will focused on the flow of Gas-Oil-Water through a vertical pipe from oil reservoir to platform located at the sea or land surface. As we all know, the petroleum are produces from organics matters where it only turn to oil and gas but not water, so the question is where the water can come from. Water is very often present in the reservoirs such as connate water and it will accompany the produced oil and natural gas, which arises naturally from the reservoir (Cazares et. al., 2010), thus producing multiphase flow.

Other than that, the water is produced due to water injection in the reservoir at a later stage of the production (Cazares et. al., 2010). This is known as enhanced oil recovery (EOR), where it is one of the ways to extract oil from oil reservoir and have been the favourite extraction method among explorer. The technique has been implemented to force oil out of the pore spaces or reservoir rock. Due to a number of complicated factors (e.g. reservoir pressure, porosity, permeability, oil viscosity, etc.), EOR technique cannot increase primary recovery by much more than an average 10–20 % of the oil in place (Sugiharto et. al., 2009).

Due the nature of the phase, we know that gas is not possible to be the carrier, so this leaves water and oil to do so. A carrier give a big effect to the flow of material across the pipe whether vertically, inclined or horizontally. If in condition of heavy oil present or extraction by enhance oil recovery (EOR), the most probable carrier will be water and in this case it is known to be Water Dominant Flow. In such system, the water can serve as carrier due to pump force for operating the system that generates high momentum to the water. Beside of this, in the closed system, the crude oil movement is slowed by friction with gas at top layer and friction at water–crude oil interface (Sugiharto et. al., 2009). The consequence of implementing EOR is that the production system will be water-dominated in character (Sugiharto et. al., 2009).

Heavy oil–water–gas three-phase flow often occurs in the petroleum industry, for example, in onshore and offshore hydrocarbon production and transportation (Cazares et. al., 2010). Variables measured in a flow, particularly in a multiphase/multi-component flow, are not constant but oscillate around a mean value, even under steady state conditions. This non-steady characteristic requires a large number of measured values to provide a statistically reliable basis for mean value calculations (Fisher, 1994).

2.4 The Modelling of Multiphase Flow With Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) is a software that can help in building model and it can help in testing the model by running it in a simulation. This CFD software are very popular among researchers because the ability for it to calculate is prove to be one of the most advance modelling and testing technique up-to-date. In this research, the CFD software that are chosen to execute the job is Gambit and Fluent where it will model the gas–liquid flow regimes. For the purpose of the characteristics analysis, the equations for the two liquids (oil and water) were combined to obtain the equations in terms of liquid mixture quantities (Cazares et. al., 2010). In general, because three-phase flow models are lacking, one treatment for three-phase flow is to combine oil and water into a single liquid phase and then modelling the system as a two-phase liquid–gas flow. In this treatment, the slip between the oil and water is ignored and a homogeneous mixture is assumed for the liquid phase (Shi et. al., 2004; Zhang and Sarica, 2005; Bonizzi and Issa, 2003). This assumption can be accepted because water and crude oil were easily mixed well, and the mixture flowed lightly. (Cui et al., 2004)

2.4.1 Governing Equation

Before any equation are made, there are a couple of variable that are neglected with the support from previous researchers. In this work, the effects of breakup and coalescence of droplets and bubbles are neglected. Other than that, chemical reaction and heat transfer between phases and between flow and pipe also have been neglected. In the model it is assumed that the drag and virtual mass forces were the only interfacial forces considered. Also with that, it is assumed that all pressure is the same while treating water and oil as incompressible. The gas-wall and the oil-wall friction shear stresses (swg, swo) were also ignored but a mixture-wall friction shear stress (sw) was used (Cazarez et. al., 2009) at the place of a water-wall friction shear stress. Then, the conservation equations of mass, momentum and energy for each phase in bubbly oil–bubbly gas three-phase flow are given by.

2.4.1.1 Mass Equations

The Equations (2.1)-(2.3) is the equations for conservation of mass for each phases in three-phase flow.

(2.1)

$$\frac{\varepsilon_g}{\rho_g C_g^2}\left[\frac{\partial P}{\partial t} + v_g \frac{\partial P}{\partial Z}\right] - \frac{\varepsilon_g}{T_g}\left[\frac{\partial T_g}{\partial t} + v_g \frac{\partial T_g}{\partial Z}\right] + \left[\frac{\partial \varepsilon_g}{\partial t} + v_g \frac{\partial \varepsilon_g}{\partial Z}\right] + \varepsilon_g \frac{\partial v_g}{\partial Z} = 0$$